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UNITED STATES PATENT APPLICATION

ON

ACOUSTICAL STIMULATION OF VAPOR DIFFUSION SYSTEM AND METHOD

BY

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82274.93 RSL

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**TECHNICAL FIELD OF THE INVENTION**

The present invention relates generally to the field  
of acoustic stimulation of fluids, and more particularly,  
5 but not by way of limitation, to an acoustical stimulation  
system and method of vapor diffusion towards a surface.

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**CROSS-REFERENCE TO RELATED APPLICATIONS**

Pursuant to 35 U.S.C. § 119(e), this application claims the benefit of U.S. Provisional Patent Application No.

60/422,970, entitled *Acoustical Stimulation of Vapor*

5 *Diffusion System and Method*, filed November 1, 2002, naming G. Douglas Meegan, Jr. inventor, which is hereby incorporated by reference for all purposes.

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**BACKGROUND OF THE INVENTION**

Fluid streams comprising small constituents are produced by many chemical and combustion processes, such as, but not limited to, particulates in the exhaust gas stream of coal fired power plants. Such constituents may include, for example, vaporous forms of these constituents. For environmental and other reasons, it may be desirable to remove these constituents. Sorbents -- the term "sorbent", including, but not limited, to both "adsorbent" and "absorbent" -- may be injected into the gas exhaust streams exiting power plant boilers to promote removal of these constituents. The dilute vapor can be removed by means of interaction of the vapor with the surface of the sorbent; however, the removal efficiency of sorbent injection can be limited, depending on a number of factors including the time the sorbent has to interact with the constituent and the entrainment of the constituents in the gas exhaust stream. A need exists for an improved system and method to promote improved removal of constituents from a fluid stream.

Additionally, in the use of the sorbent injection technology, collection devices, such as a fabric filter bag house, are frequently provided downstream of the sorbent injector. While sorbent injection is proven as one method of satisfying constituent emissions regulations -- e.g., mercury emission regulations in facilities, such as coal-fired power plants, the use of such sorbents will typically increase the frequency of bag cleaning. For example, in the use of a sorbent, such as activated carbon, to remove a constituent, such as mercury, the cleaning frequency can be tripled as a result of activated carbon

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being injected at levels required to remove about 80% total mercury. Therefore, the increase in bag cleaning frequency becomes one of the greatest concerns with the use of sorbent injection to reduce constituent emission. It is  
5 clearly necessary to develop cost-effective methods to substantially reduce or eliminate the negative effects of sorbent injection on the fabric filter cleaning frequency.

In yet other situations, sorbents may be injected into exhaust streams and collected by other means such as  
10 electrostatic precipitators, cyclone collectors, gravitational settling chambers, and others. In these cases, bag cleaning is not an issue, but the cost of sorbents can be very high for a variety of reasons. In this case it is clearly necessary to develop methods to achieve  
15 more effective mercury removal for a given amount of injected sorbent, thereby reducing costs and/or improving mercury removal.

It is to such an acoustical stimulation system and method of vapor diffusion towards a surface that the  
20 present invention is directed.

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**SUMMARY OF THE INVENTION**

In one aspect of the invention, an apparatus for removing constituents from a fluid stream is provided. The apparatus comprises a duct, a collection device, a sorbent injector, and an acoustic generator. The duct has a fluid passageway to receive a fluid stream having constituents. The collection device is coupled to the duct and in communication with the fluid passageway to filter the fluid stream. The sorbent injector injects a sorbent in the fluid passageway of the duct upstream of the collection device. The acoustic generator generates an acoustic field in the fluid passageway of the duct to promote sorption of at least some of the constituents for collection by the collection device.

In another aspect of the invention, a method is provided for removing constituents from a fluid stream. The method comprises providing a duct defining a fluid passageway; providing a fluid stream having constituents in the fluid passageway of the duct; injecting a sorbent in the fluid stream; and applying an acoustic field in the fluid stream to promote sorption of at least some of the constituents.

In yet another aspect of the invention, an apparatus is provided for removing constituents from a fluid stream. The apparatus comprises a scrubber tower, a liquid injector, and an acoustic generator. The scrubber tower has a chamber defining a fluid passageway to receive a fluid stream having constituents. The liquid injector is coupled to the scrubber tower and is operable to inject a liquid agent in the scrubber tower. The acoustic generator generates an acoustic field in the chamber of the scrubber

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tower to promote a chemical reaction with at least some of the constituents.

In yet another aspect of the invention, a method is provided for enhancing mass transfer from a dilute vapor  
5 towards the surface of a sorbent. The method comprises providing a fluid stream having a dilute vapor; injecting a sorbent having a surface into the fluid stream; and applying an acoustic field to the fluid stream to promote diffusion of the vapor toward the surface of the sorbent.

10 In yet another aspect of the invention, a method is provided for enhancing mass transfer from a dilute vapor towards the surface of a sorbent. The method comprises providing a gas stream having a dilute vapor; injecting a liquid spray into the fluid stream; applying an acoustic  
15 field to the fluid stream to promote removal of the dilute vapor; and providing a collection device to collect the liquid which has chemically reacted with the dilute vapor.

In yet another aspect of the invention, a method is provided for determining a frequency of sound to increase  
20 the acoustical stimulation of vapor diffusion. The method comprises selecting a sound pressure level of an acoustic field; calculating a time harmonic acoustic displacement of a fluid stream; calculating a time harmonic displacement of an agent particle in response to the acoustic field and an  
25 associated viscous drag effect; calculating a relative displacement amplitude of the agent particle by subtracting the displacement of the agent particle from the displacement of the fluid stream; and calculating the relative displacement over a plurality of frequencies to  
30 produce a curve such that the curve includes a global

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maximum wherein the global maximum is the sound to increase the acoustical stimulation of vapor diffusion.

In yet another aspect of the invention, a method is provided for extending the useful life of a filtration  
5 device. The method comprises providing a duct defining a fluid passageway; providing a filtration device, operable to filter a fluid stream; injecting a sorbent in the fluid stream; applying an acoustic field in the fluid stream to promote sorption of at least some of the constituents;  
10 collecting the at least some of the constituents and at least some of the sorbent with the filtration device; and removing the at least some of the constituents and the at least some of the sorbent from the filtration device to clean the filtration device.

15 In yet another aspect of the invention, a method is provided for enhancing transfer of constituents in a fluid towards a surface of a sorbent. The method comprises providing a fluid with constituents; injecting a sorbent having a surface into the fluid; and applying a modulated  
20 acoustic field to the fluid to promote transfer of the constituents towards the surface of the sorbent.

In yet another aspect of the invention, a method is provided for enhancing transfer of constituents in a fluid towards a surface of a sorbent. The method comprises  
25 providing a fluid with constituents; injecting a sorbent having a surface into the fluid; applying an acoustic field to the fluid; and frequency modulating the acoustic field to promote transfer of the constituents towards the surface of the sorbent.

30 In yet another aspect of the invention, an apparatus is provided for removing constituents from a fluid stream.



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The apparatus comprises a duct, a manifold system, a sorbent injector, and at least a first sound source. The duct has a sidewall defining a fluid passageway and is adapted to receive a fluid stream having the constituents.

5 The manifold system is coupled to the duct such that the manifold system communicates with the fluid passageway. The sorbent injector injects a sorbent in the fluid passageway of the duct. The at least a first sound source is coupled to the manifold system and operable to generate  
10 an acoustic field in the fluid passageway of the duct to promote sorption of at least some of the constituents.

In yet another aspect of the invention, an apparatus is provided for removing constituents from a fluid stream. The apparatus comprises a fluid passageway, a collection  
15 device, a substance having a reacting surface, and an acoustic generator. The fluid passageway is operable to receive a fluid stream having constituents. The collection device is in communication with the fluid passageway and is operable to filter the fluid stream. The substance  
20 having a reacting surface is operable to react with the constituents. The acoustic generator generates an acoustic field in the fluid passageway to promote reaction of at least some of the constituents with the reacting surface of the substance for collection by the collection device.

25 One advantage of the present invention is that where mercury is desirably removed, injection of activated carbon as a sorbent promotes sorption of elemental and oxidized mercury. However, application of the acoustic field provides for substantial movement and/or mixing of the  
30 constituents, including the mercury, relative to the activated carbon sorbent thus exposing the sorbent to

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portions of the fluid stream having the highest concentrations of mercury, not merely the surrounding or immediately adjacent constituents. The application of the acoustic field causes the sorbent to be exposed to various portions of the mercury entrained in the fluid stream, as  
5 opposed to only the mercury entrained in the adjacent fluid stream.

Another advantage of the present invention is that standard particulate removal of, for example, fly ash may  
10 be accomplished, for example, upstream of the mercury sorption and removal, which has the additional benefit of not contaminating the removed fly ash constituent with hazardous or undesirable constituents, such as mercury.

Another advantage of the present invention is that the  
15 present invention may be usefully employed to promote both sorption and, for example in scrubber tower, to promote enhanced sorption of, for example sulfur and nitrogen oxides, by, for example, a limestone slurry applied in the scrubber towers in power plants. This increased sorption  
20 beneficially provides for increased sorption by the limestone slurry, allowing for less slurry to be required or improved removal of the constituents, such as sulfur or nitrogen oxides, to be achieved.

Another advantage of the present invention is the  
25 ability to achieve enhanced constituent removal efficiencies with the use of substances, having removal surfaces.

Other objects, features, and advantages of the present invention will be apparent to those skilled in the art from  
30 the following detailed description when read in conjunction with the accompanying drawings and appended claims.

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**BRIEF DESCRIPTION OF THE DRAWINGS**

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following brief description, taken in connection  
5 with the accompanying drawings and detailed description, wherein like reference numerals represent like parts, in which:

**FIGURE 1** is a side view of one aspect of an acoustic agglomerator illustrating a passageway of a duct containing  
10 a fluid stream that may be utilized with the present invention;

**FIGURE 2** is a graph illustrating the advantages of acoustic modulation for acoustic agglomeration of lignite fly ash;

15 **FIGURE 3** is another graph illustrating the advantages of acoustic modulation for acoustic agglomeration of lignite fly ash;

**FIGURE 4** is a side view of a duct communicating a combustion gas stream to a filtration device;

20 **FIGURE 5** is a side view of an acoustic agglomerator provided with an acoustic generator and a filtration device for removal of particulates from a combustion gas stream that may be utilized in conjunction with the present invention;

25 **FIGURE 6** is a side view of the duct provided with a plurality of acoustic generators for generating a modulated acoustic field;

**FIGURE 7** is a side view of another acoustic agglomerator that may be desirably used;

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**FIGURE 8** is a side view of one aspect of the acoustic generator having a mechanical oscillator, a shaft and an acoustic plate;

**FIGURE 9** is a perspective view of one aspect of the acoustic plate illustrated in Figure 8;

**FIGURE 10** is a perspective view of another aspect of the acoustic generator including a plurality of sound sources and a manifold;

**FIGURE 11** is a flow-chart illustrating a method for acoustic agglomeration by modulation of the acoustic field that may be implemented in conjunction with the present invention;

**FIGURE 12** is a side view of an acoustical stimulation system 200 that increases vapor diffusion towards a surface, according to one aspect of the invention;

**FIGURE 13** is a side view of a power plant system illustrating implementation of one aspect of the present invention;

**FIGURES 14A -14D** show the use of acoustic fields to extend the life of filtration devices that collect sorbents, according to one aspect of the invention;

**FIGURE 15** is a flow-chart illustrating one aspect of a method for removing constituents from a fluid stream;

**FIGURE 16** is a flow-chart illustrating one method for selecting a frequency of a sound field to increase the acoustical stimulation of vapor diffusion; and

**FIGURE 17** is a chart, corresponding to an illustration for selecting a frequency of a sound field to increase the acoustical stimulation of vapor diffusion.

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**DETAILED DESCRIPTION OF THE INVENTION**

It should be understood at the outset that although an exemplary implementation of the present invention is illustrated below, the present invention may be implemented using any number of techniques, whether currently known or in existence. The present invention should in no way be limited to the exemplary implementations, drawings, and techniques illustrated below, including the exemplary design and implementation illustrated and described herein.

**FIGURES 1-11** are descriptions of exemplary implementations of systems and methods of acoustically agglomerating constituents and particulates that may be usefully employed in various combinations with the present invention. However, the present invention is in no way limited to these implementations and may be used alone without any acoustic agglomeration, in conjunction with these exemplary implementations of acoustic agglomeration systems and methods or with other agglomeration systems and techniques.

**FIGURE 1** illustrates one aspect of an acoustic agglomerator 10 for agglomerating constituents in a fluid. The acoustic agglomerator 10, according to one aspect, includes a duct 12 defining a passageway 14. The duct 12 is adapted to receive a fluid stream 16 containing constituents 18 of varying sizes.

The acoustic agglomerator 10 further includes an acoustic generator 20 that is adapted to generate a modulated acoustic field 22 in the passageway 14 of the duct 12. The acoustic field 22 is modulated to enhance agglomeration of the constituents 18 in the fluid stream 16.

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The duct 12, according to one aspect, may be an exhaust duct commonly used to transport combustion gas exhaust from the boilers of power generation facilities. Such power generation facilities may burn coal, lignite, or  
5 other material to produce electricity, for example. In this aspect, the fluid stream 16 may be the combustion exhaust gas from the boiler of the power generation facility flowing through the duct 12 and the constituents  
10 18 may be particles of lignite fly ash, such as when lignite is the combustion fuel. As previously discussed, it is necessary for environmental and other reasons to reduce the amount of such particles in the gas exhaust, such as the fluid stream 16. By acoustically agglomerating  
15 the exhaust gas, the constituents 18, such as the lignite fly ash, may be more effectively and efficiently captured than using conventional techniques.

Conventional power generation facilities utilize devices such as electrostatic precipitators (ESP) bag houses, cyclone separators, gravitational settling chambers  
20 and other particulate removal devices that are well known in the art. The conventional filtration devices are only effective when the size of the particulates, such as the constituents 18, are of sufficient size, such as 10 microns or larger, as previously discussed.

25 One significant advantage presented is that modulating the acoustic field 22 significantly enhances the agglomeration of the constituents 18 in the fluid stream 16 which promotes the removal of the constituents 18 in their agglomerated form by conventional filtration or other  
30 methods. While implementation may be described with respect to power plant and power generation facilities and

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agglomeration of combustion gas exhaust, for example, it should be appreciated, however, that acoustic agglomeration is in no way limited to this application and it is anticipated and within the spirit and scope of the present invention that a modulated acoustic field 22 may be applied to fluid in an unlimited number of various applications for the purposes of agglomerating constituents 18.

For example, while the fluid stream 16 is illustrated as traveling in a duct 12, in the present illustration, it is within the spirit and scope of the present invention that the acoustic field be applied to a chamber enclosing and completely retaining the fluid stream 16 or in open air applications where there is no containment of the fluid stream 16. Also, the fluid stream 16 may be an outdoor environment wherein the constituents 18 that are to be desirably removed may be pollution, biohazardous materials or chemicals in the air or environment, such as those accidentally or intentionally placed into the atmosphere that are hazardous to individuals or the environment.

The acoustic field 22 may further be applied to large areas, such as, but not limited to, within buildings or facilities where constituents 18, such as foreign particles that are desirably removed from the air, may exist and for environmental and health reasons the constituents 18 must be removed. The acoustic agglomerator 10 may further have application in industrial situations where water, such as lakes and streams, have become polluted or contaminated and the pollutant or contaminant is desirably removed.

Other applications that would benefit from the present invention include manufacturing or other facilities where airborne particles require filtration for health, safety,

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and other reasons, such as within manufacturing facilities or otherwise. Additional applications include, for example, exhaust systems of conventional combustion engines used in the automotive industry to reduce dangerous and  
5 hazardous pollutants before being expelled into the atmosphere. Furthermore, while the fluid stream 16 may be illustrated as gas exhaust, in other aspects the fluid stream may be a gas or a liquid.

As previously discussed, applying a modulated  
10 acoustic field 22 promotes agglomeration since the smaller particles move in response to the acoustic wave more so than larger particles which result in more collisions of the larger and smaller particles. Once the collision occurs, electrostatic force promotes retention of the  
15 particles. Although sinusoidal waves produced by various sound sources may produce limited agglomeration, the present invention illustrates that dramatic agglomeration may be achieved by modulating the acoustic field 22. It will be appreciated, however, that the preferable frequency  
20 and amplitude of the acoustic field 22, as well as the modulation range, is heavily dependent upon the type of particulate matter, such as the constituents 18, that are desirably agglomerated.

**FIGURE 2** and **FIGURE 3** illustrate application of  
25 acoustic field 22 to promote agglomeration of lignite fly ash and the effects of applying a modulated acoustic field 22. The basis for these measurements include that the exhaust gas containing the fly ash was moving through the duct 12 at a rate of approximately 3 feet per second. The  
30 No Sound 24 measurement represents the particulate size of the combustion gas exiting from the boiler without the



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application of an acoustic field 22. The sinusoid 26 measurement includes application of a sinusoidal wave applied at approximately 600 Hz to the combustion gas exhaust and illustrates the resulting size of the  
5 particulate matter agglomeration. The modulation measurement 28 illustrates the effects of agglomeration by application of a modulated acoustic field 22 having a sound pressure level of approximately 150 dB referenced to 20 micro-Pascals at approximately 600 Hz modulated plus or  
10 minus 150 Hz. It will be appreciated, however, that the desired range of frequency and sound pressure level modulation should in no way be limited to the present example and many other ranges of modulation and settings of the frequency and sound pressure levels may be used  
15 according other aspects of the present invention.

It can be seen that application of a modulated acoustic field 22 to the fluid stream 16, such as the combustion gas exhaust containing constituents 18 of lignite fly ash, significantly enhances agglomeration and  
20 increases the mass of the particulate which promotes more effective and efficient removal by conventional filtration techniques as previously described. It can be seen that, for example, .5 to 2 micron particles in size may be effectively agglomerated to, for example, about 2 to 5  
25 microns in size by application of a modulated acoustic field 22.

It will be appreciated that a bag house or ESP responds readily to this size and effectively eliminates particles in the 2 to 5 micron range. Although an ESP is  
30 effective at removing larger particulate matter, a significant amount of the smaller particulate are

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unaffected and causes emission and environmental problems, such as increased levels of opacity. In one aspect, application of the modulated acoustic field 22 may provide additional benefits, such as advantageously moving  
5 particles trapped in nodal positions. By changing the frequency the nodal position is shifted which further promotes agglomeration of the particulate matter.

Modulation of the acoustic field 22 may be accomplished by modulating the frequency of the acoustic  
10 field 22, or the amplitude of the acoustic field 22, or a combination of modulating both the frequency and the amplitude of the acoustic field 22. Such a modulation can be accomplished with only a single sound source; or, multiple sound sources can also be used. For example, to  
15 generate a frequency modulated sound field with a single sound source, the pitch generated by that single sound source would be changed in time. To generate a amplitude modulated sound field with a single sound source, the amplitude generated by that single sound source would be  
20 changed in time. The same modulations can be accomplished with multiple sound sources, where all the sound sources modulate in the same way, or differently.

Depending upon the type of constituents 18 desirably removed from the fluid stream 16 a number of combinations  
25 of frequency and/or amplitude modulation may be desirably achieved to promote and optimize agglomeration. Although the above frequency and amplitude ranges may be desirable, according to one aspect for agglomerating lignite fly ash in a combustion gas exhaust stream, it will be appreciated  
30 that in other applications the range of frequency and amplitude may change significantly.

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For example, the acoustic field 22, according to one aspect, may be frequency modulated in a range of up to 1 GHz and the amplitude of the acoustic field may be modulated in a range of up to 200 dB. In other aspects the frequency of the acoustic field 22 may be modulated in a range of up to 20 kHz and the amplitude of the acoustic field 22 may be modulated in a range of up to 200 dB. According to other aspects, the frequency of the acoustic field 22 may be preferably modulated in a range of from about 50 Hz to about 15 kHz and amplitude modulated in a range of from about 130 dB to about 175 dB.

The modulation of the acoustic field 22, according to one aspect, may preferably have an initial frequency such that the acoustic field 22 is thereafter frequency modulated relative to the initial frequency to a first frequency substantially less than the initial frequency while in other aspects the first frequency may be substantially greater than the initial frequency. According to other aspects, the frequency may be preferably modulated to a first frequency substantially greater than the initial frequency and thereafter modulated to a second frequency substantially less than the initial frequency, while in other aspects it may be preferable to modulate the acoustic field 22 to a first frequency substantially less than the initial frequency and thereafter to a frequency substantially greater than the initial frequency.

**FIGURE 4** illustrates a side view of a conventional exhaust duct 12 having an electrostatic precipitator (ESP) 40 disposed in the duct 12 such that the fluid stream 16 communicates through the passageway 14 to the ESP 40. The ESP 40, as previously discussed, is a well known

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conventional filtration system capable of removing constituents 18 of a certain size. However, the ESP 40 is ineffective for removing constituents 18 of smaller size, as illustrated.

5       **FIGURE 5** illustrates a perspective view of the acoustic agglomerator 10 utilized in a gas exhaust duct 12, substantially as illustrated in Figure 4. In this aspect it can be seen that application of a modulated acoustic field promotes agglomeration of the constituents 18 which  
10 aids the ESP 40 in removing more of the constituents 18, such that only a fraction of the smaller constituents 18 are allowed to escape through this process.

Although the acoustic generator 20 is shown disposed substantially perpendicular to the direction 42 of the flow  
15 of the fluid stream 16, it should be appreciated that the acoustic generator 20 may be disposed longitudinally to the direction 42 of flow of the fluid stream 16 or, according to other aspects, at an angle arbitrary to the direction 42 of the flow of the fluid stream 16. It should also be  
20 appreciated that the frequency of the acoustic field may be modulated exponentially, linearly, non-linearly, or applied for a periodic interval, according to other aspects of the present invention, to preferably achieve acoustic agglomeration of constituents 18 to a predetermined size.

25       This presents another significant advantage of the present invention in that by modulating the acoustic field 22 according to different frequency and amplitude modulation ranges, the constituents may be agglomerated to a preferably size to optimize the removal of the  
30 constituents 18 in the fluid stream 16. This may be useful where the constituents 18, such as lignite fly ash, may be

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valuable for resale or reuse or otherwise but only where the lignite fly ash, for example, is of a predetermined size. The present invention is capable of applying a modulated acoustic field 22 to agglomerate particulate to a  
5 desired size.

**FIGURE 6** illustrates another aspect of the an acoustic agglomerator 10 including a plurality of acoustic generators 20 disposed along the duct 12 such that the acoustic generators 20 are operable to produce a modulated  
10 acoustic field 22 within the passageway 14 of the duct 12. It can be seen that, according to one aspect, it may be preferable to provide a plurality of acoustic generators to apply a plurality of acoustic fields 22 to optimize the agglomeration of the constituents 18 in the fluid stream  
15 16.

In this aspect, the acoustic field 22 generated by each of the acoustic generators 22 may be modulated according to a predetermined frequency and/or amplitude for optimum agglomeration. The predetermined characteristics  
20 of the acoustic field 22, including the initial amplitude and frequency, as well as the modulation ranges, may, according to some aspects, include providing an acoustic field 22 produced by each of the acoustic generators that is substantially similar, while in other aspects the  
25 acoustic field 22 generated by each of the acoustic generators 20 may be different, while in yet other aspects some of the acoustic fields 22 may be similar while others may have different acoustic characteristics.

Furthermore, by positioning the acoustic generators 20  
30 to optimize agglomeration prior to the fluid stream 26 entering the ESP 40, an optimum amount of agglomeration and

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resulting removal of constituents 18 may be achieved.  
According to other aspects, additional acoustic generators  
20 such as the acoustic generator 20A may be provided  
downstream of the ESP 40 and prior to other filtration  
5 devices, such as a bag house 44.

The bag house 44 may include a filter operable for  
collecting constituents 18 of a specific size such that the  
filter may be emptied from time-to-time when the filter  
becomes full or ineffective because it is clogged. Another  
10 advantage of the present invention is that the  
agglomeration may achieve constituents 18 of a desired  
size, such as constituents 18 large enough not to become  
lodged within the filtration membrane, for example,  
utilized by the bag house 44.

15 Therefore, the bag house 44 may be optimally emptied  
of larger agglomerated constituents 18 as opposed to being  
discarded when the smaller constituents 18 become lodged in  
the membrane of the filtration portion of the bag house 44.  
Otherwise, the filtration portion of the bag house 44 is  
20 rendered ineffective and must be discarded. Thus,  
utilization extends the life and reduces the costs of  
certain conventional filtration devices further reducing  
the costs and promoting the efficiency of, for example,  
conventional power plant filtration components.

25 Furthermore, application of acoustic agglomeration,  
upstream from the bag house can reduce the required  
frequency of cleaning because larger agglomerated particles  
tend to more slowly clog the filter material. This effect  
has been measured during various slip-stream tests at coal-  
30 fired power plants. This provides another advantage since  
it is well known that a reduction in cleaning frequency can

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improve bag lifetime because the cleaning process  
(compressed air and/or shaking) can be destructive.

**FIGURE 7** illustrates another aspect of the acoustic  
agglomerator 10 is further provided with a power amplifier  
5 50 in communication with the acoustic generator 20. The  
power amplifier is operable to amplify the power output of  
the acoustic generator 20. The acoustic agglomerator 10  
further provided with a function generator 52, the function  
generator 52 is operable to generate frequency modulation  
10 of the acoustic field 22 produced by the acoustic generator  
20. The acoustic agglomerator 10 is further provided with  
an opacity detector 54 in communication with the passageway  
14 of the duct 12 and operable to detect the opacity of the  
fluid stream 16.

15 The acoustic agglomerator 10 is further provided with  
a particulate analyzer 56 operable to obtain information  
with respect to the constituents 18 such as, but not  
limited to, the size of the constituents 18. Utilizing the  
opacity detector 54 and the particulate analyzer 56, the  
20 acoustic agglomerator 10 may operably determine information  
about the fluid stream 16 and the constituents 18 contained  
in the fluid stream 16 and in response to, for example,  
undesirable opacity levels and/or particulate size of the  
constituents 18, the acoustic field 22 may be modified,  
25 such as the frequency and amplitude as well as the  
modulation, to optimize the agglomeration of the  
constituents 18.

**FIGURE 8** illustrates another aspect of the  
agglomerator 20. The agglomerator 20 includes a mechanical  
30 oscillator 60, a shaft 62, and a plate 64. The plate 64 is  
configured for acoustic generation and may be constructed

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from a variety of materials such as metal or polymeric materials, for example. The shaft is provided with a first end 66 connected to the acoustic plate 64 and a second end 68 connected to the mechanical oscillator 60. The  
5 mechanical oscillator 60 is operable to impart a mechanical oscillation on the second end 68 of the shaft 62 and to the acoustic plate 64 connected to the shaft 62 to generate a modulated acoustic field 22.

The acoustic plate 64, according to this aspect, is  
10 disposed within the passageway 14 of the duct 12, as illustrated in partial cutaway in the present view. The shaft 62 projects through an opening 70 in the duct 12 such that the acoustic plate 64 may be oscillated to produce the modulated acoustic field 22 within the duct 12.

15 **FIGURE 9** illustrates one aspect of the acoustic plate 64 shown in Figure 8. In this view, it can be seen that the acoustic plate 64 may be configured in a variety of manners including substantially arcuate or flat. A first side 80 of the acoustic plate 64 is provided with a  
20 plurality of ribs 82. In other aspects, the acoustic plate 64 may be constructed in a substantially honeycomb configuration 84 throughout, although only a portion is illustrated in the present view.

Depending upon the different configurations of the  
25 acoustic plate 64, various frequencies and modulation ranges may be preferably achieved, such as when the acoustic plate 64 is oval versus substantially circular or rectangularly configured. Although a variety of configurations of the acoustic plate 64 may be utilized and  
30 are within the scope of the present invention, no further



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description of acoustic plate 64 configurations will be described for purposes of brevity.

**FIGURE 10** illustrates another aspect of the acoustic generator 20. In this aspect the acoustic generator 20 is defined as an electrodynamic compression driver array provided with a plurality of sound sources 100, each operable for generating a modulated acoustic field 22. The acoustic generator 20 further includes a manifold 102 having a main chamber 104 and a plurality of chamber ports 106 in communication with the sound source 100 and the main chamber 104.

The manifold may be constructed from a plurality of materials such as metal, aluminum, cast-aluminum and serves as a thermal conductor and/or radiator that isolates the sound sources 100, such as compression drivers, from elevated temperatures. The end 108 of the manifold 102 is operably coupleable to the duct 12 in an airtight fashion and has provisions for pressure equalization between the front and back of the diaphragms (not shown) of the sound sources 100, such as the compression driver diaphragm. Another provision of the compression driver (described only briefly here) allows the sound sources 100 to be tuned electrically and mechanically to most efficiently generate sound within a 10% band of a specific center frequency. The center frequency may be adjusted through a manual or automatic tuning of individual sound sources 100 within the array.

It should be appreciated that either the acoustic generator 20 illustrated in Figures 8 or 10 may be utilized with the acoustic agglomerator 10 and that, in some aspects, a plurality of acoustic generators 20 configured

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as illustrated in Figures 8 and 10 may be utilized as well. Although the acoustic generator 20 illustrated in Figure 10 may be shown with a plurality of sound sources 100 coupled to the manifold 102, it will be appreciated in other  
5 aspects that only a single sound source 100 is coupled to a single manifold 102 while in other aspects a greater number of sound sources 100 may be coupled to a manifold 102 configured to receive a plurality of sound sources 100.

Furthermore, the configuration of the manifold 102, as  
10 illustrated in Figure 10, represents only one possible configuration in the manifold 102 and a variety of manifold 102 configurations may be utilized and are sufficient for the purposes of the present invention and are within the spirit and scope of the present invention. It should also  
15 be appreciated that although the acoustic generators 20 illustrated in Figures 8 and 10 may be preferably utilized, in some aspects, a variety of sound source 100 configurations may be utilized so long as a given sound source is operable to produce a modulated acoustic field  
20 22.

**FIGURE 11** illustrates a method 120 for agglomerating constituents 18 in a fluid, such as the fluid stream 16. At a first block 122 the method includes providing a fluid having constituents 18. In this block 122, as previously  
25 discussed, the fluid having constituents 18 may be in an open air environment, within a facility or building, or within an enclosed duct 12 or passageway 14. As previously discussed, the fluid stream 16 may include a gas or a liquid and the constituent 18 may be any type of material,  
30 whether liquid, gaseous or otherwise, provided in the fluid

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stream 16 that is desirably agglomerated for removal or other purposes.

At a block 124, the method includes applying an acoustic field 22 to the fluid stream 16. In this aspect  
5 the method may include, according to some aspects, including one or more acoustic generators 20 operable for generating a modulated acoustic field. At a block 126, the method provides for modulating the acoustic field 22.

As previously discussed, the acoustic field 22 may be  
10 amplitude modulated, frequency modulated or a combination of both frequency and amplitude modulated. Furthermore, in aspects where a plurality of acoustic generators 20 are utilized, a plurality of acoustic fields 22 each having varying characteristics of amplitude and frequency  
15 modulation may be employed. In aspects employing a plurality of acoustic generators 20, some of the acoustic generators 20 may produce acoustic fields 22 that may not necessarily be modulated.

**FIGURE 12** is a side view an acoustical stimulation  
20 system 200 that increases vapor diffusion towards a surface, according to one aspect of the invention. The acoustical stimulation system 200 includes the duct 12 defining the passageway 14 for communicating the fluid stream 16 containing the constituents 18. According to  
25 this aspect of the present invention, the constituents 18 may be sulfur oxides, nitrogen oxides, elemental or oxidized mercury or other constituents that may be desirably removed from the fluid stream for environmental and other reasons.

30 The acoustical stimulation system 200 in this aspect of the invention utilizes a reacting surface to facilitate

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removal of the constituent 18. The reacting surface in this aspect of the invention is a surface 208 of a sorbent 204, which is injected into passageway 14 with a sorbent injector 202. The sorbent injector 202 can be any device  
5 capable of injecting the sorbent 204 into the passageway 14; and, the sorbent 204 can be any of the typical sorbents 204 now known or later developed, including, but not limited to, activated carbon. While a sorbent injector 202, which injects a sorbent 204, has been shown in this  
10 aspect of the invention, other aspects of the invention may utilize other reacting surfaces, including, but not limited to chemical spray injections, fixed-bed adsorbers, catalytic converters, packed scrubber towers, and the like. The sorbent injector 202 may be provided on or adjacent to  
15 the duct 12 -- so long as it is operably located to inject the sorbent 204 upstream (or co-located with) the acoustic generator 20 or sound source. The acoustic generator 20 may be similar to the acoustic generator 20, described above with reference to FIGURES 1-11, or other sound  
20 sources operable to generate an acoustic field 206 having a sound pressure level, which according to some aspects, may be in a range of from about 130 to 170dB at 20 microPascals and have a frequency in a range of from about 5Hz to 30kHz.

It should be expressly understood that the acoustic  
25 field 206 in some aspects of the invention may not be modulated, while in other aspects of the invention the acoustic field 206 can be modulated. Additionally, in some aspects of the invention, the acoustic field 206 may have a waveform defined as being sinusoidal, while in other  
30 aspects of the invention, the waveform may be a periodic waveform. In yet other aspects of the invention, the

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acoustic field may be a combination of any of the above variations of the acoustic field 206, including variations described with reference to Figures 1-11. Although only one acoustic generator 20 is illustrated in the present view, in other aspects of the invention of the invention, a plurality or an array of acoustic generators 20 may be utilized in various configurations and dispositions to produce acoustic fields 206 having similar or varying acoustic characteristics.

The present view illustrates the constituent 18, which may be entrained in the fluid stream 16, provided in the fluid passageway 14. The constituents 18 are at a point where the sorbent 204 is injected in the fluid passageway 14. Absent the presence of the acoustic generator 20, it will be appreciated that given an unlimited amount of time and/or distance in the fluid passageway 14, a considerable amount of the constituent 18 may potentially be sorbed by the sorbent 204; unfortunately, due to the limited distance in the duct 12 and time relative to the travel of the fluid stream 16 down the duct 12, only a small amount of the constituent 18 may have time to be sorbed by the sorbent 204. As such, an enhancement may be necessary to increase such sorption. Additionally, in some aspects of the invention, an enhancement may be the only way in which a desired level of constituents 18 can be removed.

It is to such an enhancement, and for other reasons, that one aspect of the present invention is provided to increase sorption of the constituents 18. This aspect of the invention provides for application of the acoustic field 206, which creates a stirring or mixing of the constituents 18 relative to the sorbent 204 to expose, for

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example, an increased amount of the constituents 18 to the sorbent 204. This novel technique causes the fluid stream 16, such as a gas exhaust, containing the constituents 18 to move substantially relative to the sorbent 204,

5 substantially promoting increased vapor diffusion of the constituents 18 toward the surface 208 of the sorbent 204.

The acoustic stimulation system 200 can include an emissions analyzer 58 (such as a mercury analyzer or a sulfur oxide analyzer or a nitrogen oxide analyzer, particle  
10 analyzer, opacity detector, etc.) help to determine the characteristics of the fluid stream 16. In a manner similar to that described above, with reference to Figure 7, information from the emissions analyzer 58 can be communicated to the acoustic generator 20 to allow the  
15 acoustic field 206 to be adjusted - for example, by frequency, amplitude, or modulation; and, in some aspects of the invention, adjustments can be made to the sorbent injector 202 based on readings from the emissions analyzer 58.

20 As shown in this aspect of the invention, the acoustical stimulation system 200 can additionally include a baghouse 44 and a hopper 210 for collection of the sorbent 204 containing the sorbed constituent 18. While the baghouse 44 and hopper 210 have been shown in this  
25 aspect of the invention, it will be appreciated by one of ordinary skill in the art that a number of other collection and filtration devices may be utilized as well.

The use of the stimulation system 200 can be used independently of other current method and techniques used  
30 to capture undesirable or potentially hazardous constituents 18. For example, the acoustical stimulation

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system 200 may be utilized in conjunction with the other systems, such as those described with reference to Figures 1-11, or other current particle collection devices, such as electrostatic precipitator and baghouses, or systems  
5 located remotely from acoustical stimulation system 200 -- the other systems being, for example, upstream or downstream of the acoustical stimulation system 200. This can allow for continued capture of, for example, fly ash, while allowing for additional removal of, for example,  
10 mercury -- thus, eliminating the potential of contaminating the fly ash with mercury or other hazardous materials.

In one aspect of the invention, the acoustical stimulation system 200 can be operably employed on a scrubber tower (not shown) whereby a liquid spray, such as  
15 a limestone slurry, is used to reduce constituents 18, such as sulfur oxides and/or nitrogen oxides. The sorbent 204, in this instance, is the limestone slurry. Application of the acoustic field 206 generated by one or more acoustic generators 20 increases the sorption of the constituents 18  
20 by the sorbent 204. Thereafter the sorbent 204 may be desirably removed utilizing known techniques.

One advantage of employing the present invention is that more sorption by the sorbent 204 of the constituents 18 may be achieved further reducing the constituent 18,  
25 such as sulfur oxide, in the fluid stream 16 for environmental and other reasons. As briefly mentioned above, such an enhanced sorption may be the only way in which a desired removal level of constituents 18 can be obtained. Also, because the sorbent 204 sorbs more of the  
30 constituent 18 less sorbent 204 may be necessary to achieve

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the same constituent 18 reduction achieved by prior systems, thereby providing a cost savings.

**FIGURE 13** illustrates a power plant 300, such as a coal-fired power plant, wherein the present invention may be employed. The power plant 300 may include a boiler 302, a heat exchanger 304, a particulate collection device 306, a baghouse 308, a scrubber tower 310, and a stack 312. The duct 12 communicates the gas exhaust or fluid stream 16 (not shown, but seen, e.g., in Figure 12) between the several devices. It will be appreciated that a number of power plant configurations are or may be employed that may be similar or different to the power plant 300 illustrated. However, the present view of the power plant 300 is provided to illustrate implementation under various scenarios of the present invention.

In this illustration, the acoustical stimulation system 200 (not shown) may be coupled to or within the scrubber tower 310 for removal of constituents 18 (not shown -- but, for example, sulfur). The acoustical stimulation system 200 (not shown) may be employed on the duct 12 between the particulate collection device 306 and the baghouse 308 or on the duct 12 downstream of the baghouse 308 or in some aspects, upstream of the particulate collection device 306.

In one aspect, the acoustic agglomerator 10 (not shown) may be coupled to, for example, the duct 12 upstream of the particulate collection device 306 for agglomeration and removal of particulate matter, such as fly ash, and the acoustical stimulation system 200 (not shown) may be employed downstream of the particulate collection device 306 for removal of constituents 18 (not shown -- but, for



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example, mercury). In other aspects, the acoustical stimulation system 200 (not shown) may also be employed in the scrubber tower 310 to promote sorption of, for example, nitrogen and/or sulfur oxides. In any event, it should be appreciated that the present invention is in no way limited to the acoustic agglomerator 10 (not shown) or to power plant implementations and the present invention may be used in numerous commercial and other applications, such as waste incinerators or in catalytic devices.

**FIGURES 14A -14D** show the use of acoustic fields 206 to extend the life of filtration devices that collect constituents 18 (such as fly ash) and/or sorbents 204, according to one aspect of the invention. As indicated in the background of the invention, a promising method for the capture of constituents 18 (e.g, mercury or the like) in a facility such as coal-fired power plants involves the use of a sorbent injector 202 that continuously injects a sorbent 204 (e.g., 5-30 micron activated carbon particles) upstream of a bag or fabric filter 48. Illustration of this process is shown with reference to Figure 14A.

Generally, the duct 12 defines a passageway 14 for communicating the fluid stream 16 containing the constituents 18. After injection of the sorbent 204 via sorbent injector 202, the sorbent 204 along with constituents 18 (such as fly ash) build up in a cake on the fabric filter 48 in a bag house 44. The fabric filter 48 is cleaned periodically by various methods (e.g., typically, compressed air blows into the bag opposing the flue gas flow) when the pressure drop across the fabric filter 48 reaches a predetermined point. One aspect of the present invention can reduce the negative impact of sorbent

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injection on bag filters 48 and improve removal of constituent 18 by permitting thicker sorbent cake buildup at a reduced differential pressure. While such an aspect is disclosed with regards to sorbent injection, it should  
5 be understood that in yet another aspects of the present invention (e.g., when sorbent is not injected) reduction of the negative impact of fly ash on bag filters can still be obtained -- for example, similar to that described above with reference to Figure 6. In such aspects, removal of  
10 constituent 18 is permitted via thicker fly ash cake buildup at a reduced differential pressure.

The basic concept of the above aspect with regards to sorbent injection is illustrated with reference to Figure 14B. By exposing the constituent 18 (e.g., fly ash) and  
15 sorbent 204 to the acoustic field 206 (e.g., typically 1-2 seconds of exposure to the acoustic field 206 ) from an acoustic generator 20, the rapid formation of agglomerates occurs. Tightly packed agglomerates lead to the formation of a more porous filter cake. The porous cake can build up  
20 to greater thickness before cleaning is required, thereby increasing the time between cleanings. In a specific use (e.g. coal-fired power plants with removal of mercury desired), the acoustic effect on caking is largely independent of the type of coal being burned and the  
25 relative speciation of the mercury. The improved filter cake porosity can cause several desirable effects including, but not limited to, the slower buildup of pressure-drop across the fabric filter 48, the buildup of a thicker sorbent and/or fly ash cake on the fabric filter  
30 48, the reduction of frequency of cleaning, the reduction of maintenance, and the buildup of a increased capture of

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the constituent 18 (e.g., mercury and fly ash particulate) due to thicker sorbent cake.

With reference to Figures 14C and 14D, illustrative data is shown from a slip-stream test. Figure 14C shows  
5 representative data of bag cleaning with and without a sound field 206 - e.g, from the acoustic generator 20 of Figure 14B. In the chart of Figure 14C, time is referenced against a change in pressure  $\Delta P$  -- the change in pressure  $\Delta P$  from approximately 1.5 to 5 indicating that the  
10 bag or fabric filter 48 needs to be cleaned. The time between bag cleanings (referenced by  $T_0$  and  $T_1$ ) is shown before and after application of a sound field 206 (indicated by arrow 140). The time between bag cleanings is more than doubled by application of the sound field 206  
15 upstream of the fabric filter 48.

Figure 14D shows a much larger data set that includes several different acoustic frequencies of the sound field 206. In this particular illustrative aspect, the lowest acoustic frequency (231 Hz) most dramatically increases the  
20 bag cleaning period (or, equivalently, decreases the bag cleaning frequency). The data in Figure 14C between times 17:20 to 18:15 shows that the application of sound field 206 causes a gradual increase in the cleaning period. Several bag cleaning cycles may be necessary before the  
25 full benefit is realized -- a near tripling of cleaning period. Such a gradual increase indicates that the structure of the bag cake is gradually transformed as repeated cleaning cycles remove past caking by individual particles and replace them with larger agglomerates.

30 **FIGURE 15** is a flow-chart illustrating one method 400 for removing constituents from a fluid stream. The method

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400 includes, at a block 402, providing a duct defining a fluid passageway and providing a fluid stream having a constituent in the fluid passageway of the duct. The method 400, at a block 404, further provides for injecting a sorbent in the fluid stream. The method 400, at a block 406, provides applying an acoustic field in the fluid stream to promote sorption of at least some of the constituents. In the step of block 406, the acoustic field can be any of the acoustic fields, describe herein - modulated, non-modulated, and the like. At a block 408, the method 400 also provides for collecting the sorbent 204, such as by the particle collection device, for example, the baghouse 44 or any of the other collection devices, described herein.

**FIGURE 16** shows a flow-chart of a method 500 of determining a frequency of sound to increase the acoustical stimulation of vapor diffusion, according to an aspect of the invention. Given a certain set of parameters, the simple arbitrary choice of a frequency can degrade performance of a vapor diffusion towards a surface -- or, at the least, produce no improvement of vapor diffusion. Contrariwise, the selection of an appropriate frequency for a given set of parameters can maximize performance of the vapor diffusion towards a surface. A flow-chart for a method of maximizing such a vapor diffusion performance is shown in FIGURE 16. According to this aspect, the method 500, at block 502, provides for selecting a sound pressure level of an acoustic field. The method 500, at block 504, provides for calculating a time harmonic acoustic displacement of a fluid stream. The method 500 includes, at a block 506, calculating a time harmonic displacement of

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a sorbent particle (or spray droplet) in response to the acoustic field and any associated viscous drag effect. In the step of block 506, the sorbent particle (or spray droplet) can be approximated as a rigid sphere of uniform density; additionally, laminar flow can be assumed. The method 500, at a block 508, includes calculating a relative displacement amplitude of the sorbent particle (or spray droplet) by subtracting the displacement of the sorbent particle from the displacement of the fluid stream.

At a block 510, the method 500 further provides for calculating the relative displacement over a plurality of frequencies to produce a curve such that the curve includes a global maximum wherein the global maximum is the frequency to increase the acoustical stimulation of vapor diffusion.

**FIGURE 17** is a chart, corresponding to another method of determining a frequency of sound to increase the acoustical stimulation of vapor diffusion, according to an aspect of the invention. In this aspect of the invention, the fluid is a gas. Due to viscosity in the flue gas surrounding an injected sorbent particle, the sorbent will move in response to the sound field. One of the simplest descriptions of the particle's motion is given by following equation:

$$m_p \frac{du_p}{dt} = 6\pi\mu r_p (u_{\text{gas}} - u_p)$$

where  $u_p$  is the velocity (i.e., meters per second) of the particle as a function of time  $t$ . For a sinusoidal sound field, the preceding equation has solutions of the form

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$$u_p = \eta U_{gas} \sin(\omega t - \phi)$$

where  $\omega$  is the angular frequency, the entrainment coefficient  $\eta$  is:

$$\eta = \frac{1}{\sqrt{1 + \omega^2 \tau^2}}$$

and the particle relaxation time  $\tau$  is:

$$\tau = \frac{2 \rho_p r_p^2}{9 \mu}$$

and  $U_{gas}$  is the velocity amplitude of a sinusoidal acoustic wave which can be related to the sound pressure level (SPL) according to:

$$p = \rho c U_{gas}$$

$$SPL = 20 \log_{10}(\langle p \rangle_{rms} / p_{ref})$$

where  $p$  is the acoustic pressure,  $\langle \rangle_{rms}$  denotes calculation of the root mean square,  $p_{ref} = 20$  microPascals,  $\rho$  = gas density, and  $c$  = the speed of sound. The displacement of the particle  $\xi_p$  (i.e., in meters) as a function of time is:

$$\xi_p = u_p / \omega$$

where  $\omega$  is the angular frequency. The displacement of the particle relative to the surrounding flue gas is:

$$\Delta x = |U_{gas} - u_p| / \omega$$

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The relationships above can be used to calculate the curves shown in the FIGURE 17. Line 610 line shows the acoustic displacement of the gas in response to an applied sound field of 150 dB. Line 620 shows the relative  
5 displacement ( $\Delta x$ ) of a 15 micron diameter activated carbon particle having 750 kg/m<sup>3</sup> density when 150 dB sound is applied. At very low frequencies, viscosity dominates and the result is that the particle moves very little relative to the surrounding flue gas ( $\Delta x$  is small because there is  
10 very little particle slip). At very high frequencies, the sound field slips past the particle, but the actual displacement is very small because of the  $1/\omega$  dependence on frequency. A frequency of about 500 Hz maximizes the displacement. The displacement (for 150 dB) is about 0.3  
15 millimeters, which is equivalent to 20 particle diameters.

It should be expressly understood that the method 500, above, and the theoretical model, described with reference to FIGURE 17, are only examples of methods for determining a frequency. The present invention should in no way be  
20 limited to these methods of frequency selection as others should become apparent to one of ordinary skill in the art. For example, in other aspects of the invention, the selected frequency can dynamically change, based upon potentially changing characteristics of the fluid stream 16  
25 as measured by an emissions analyzer 58 (Figure 12) - the selected frequency responsive to changing characteristics of the fluid stream 16. In yet other aspects of the invention, the frequency can be selected by trial and error or automated frequency scanning control methods.

30 Thus, it is apparent that there has been provided, in accordance with the present invention, an acoustical

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stimulation of vapor diffusion system and method that satisfies one or more of the advantages set forth above.

Although the preferred embodiment has been described in detail, it should be understood that various changes,

5 substitutions, and alterations can be made herein without departing from the scope of the present invention, even if all of the advantages identified above are not present.

The various embodiments shown in the drawings herein

illustrate that the present invention may be implemented

10 and embodied in a variety of different ways that still fall within the scope of the present invention.

Also, the techniques, designs, elements, and methods described and illustrated in the preferred embodiment as discrete or separate may be combined or integrated with

15 other techniques, designs, elements, or methods without departing from the scope of the present invention. Other

examples of changes, substitutions, and alterations are

readily ascertainable by one skilled in the art and could

be made without departing from the spirit and scope of the

20 present invention.